URBANIZATION IN THE ETOWAH RIVER BASIN: EFFECTS ON STREAM TEMPERATURE AND CHEMISTRY

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REFERENCE: Proceedings of the 2001 Georgia Water Resources Conference, held March 26-27, 2001, at the University of Georgia, Athens, Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, the University of Georgia, Athens, Georgia.

Abstract. Urbanization represents one of the fastest land cover transformations in Georgia and around the world. Conversion of previously forested or agricultural watersheds to residential and industrial/commercial land use affects the hydrology and geomorphology of receiving streams. These changes may contribute to alteration in stream chemistry and temperature as well. We measured monthly baseflow water chemistry and took hourly temperature data for 1 yr in 30 tributaries to the Etowah River. The thirty watersheds had variable land cover from 5 to 61% urban (27 to 80 % forested). We used a combination of multivariate and regression analysis to analyze relationships between chemistry, temperature, and land use. Watersheds with greater urban land use had higher mean soluble reactive phosphorus, nitrate, and ammonium concentrations, as well as greater specific conductance, and turbidity. Urban land use was the best predictor of phosphorus, whereas agricultural land use was the best predictor of ammonium. Nitrate concentration and conductance were best predicted using a combination of urban and agricultural land use. Increases in non-forested land use also affected stream temperature: annual mean daily temperature increased with deforestation, daily mean temperatures in summer increased with urban land use; and winter mean daily temperature increased with riparian agriculture. The changes in chemistry and temperature indicate that land use change affects the physical and chemical habitat of streams. Such changes have serious implications for native stream biota.

INTRODUCTION

Changes in land use are a necessary accompaniment to human population growth. Urban land use increases as human population centers expand and agricultural land uses accompany this growth to meet ever-increasing human food demands. All of these land transformations have impacts on stream ecosystems – either directly or indirectly (Hynes 1960, Allan 1995). The study of the relationship between land use change and stream ecosystems is receiving greater attention as land use planners and managers struggle to maintain environmental quality in the face of ever-increasing demands on natural resources.

Urbanization is one of the fastest growing land use transformations. Soon, more than 50% of the world's population will live in or around urban centers (UN 1997). Already, more than 75% of the US population lives in cities (US Census Bureau 2000). Urbanization has been shown to affect a number of stream attributes including hydrology (Leopold 1968), geomorphology (Hammer 1972), chemistry (Meybeck 1998), and biology (Lenat and Crawford 1994). The threat posed by urbanization is one that is likely to plague water quality managers and land use planners for a long time. Therefore, in order to protect stream quality, it is important to understand regional relationships between land use and stream ecosystem response.

We studied 30 tributaries of the Etowah River along an urban land use gradient associated with metropolitan Atlanta. The study is described in detail in this volume (Leigh et al. 2001). This paper summarizes the results directed at one basic question: What predictive relationships exist between urbanization in this region and water chemistry and temperature parameters?

METHODS

The thirty study streams were all within the Etowah River Basin in northeast Georgia. Study design and land use for each site are explained in detail by Leigh et al. (2001) in this volume. Basin area, relative relief (basin relief/basin perimeter), and local relief (total relief adjacent to the study site) were measured from USGS 1:24000 DRG maps using ARCVIEW software (ESRI, Inc.). Chemistry and temperature were sampled over one year at all 30 sites. Water chemistry was taken monthly during baseflow (defined as days for which there had not been significant rainfall during the previous 72 hr and for which a central USGS gage showed minimal discharge change over that same time period) from May 1999 – June 2000. Grab samples for soluble reactive phosphorus (SRP), nitrate, and ammonium were taken from 0.6 depth in the thalweg. Samples were drawn into acid-washed 60ml polyethylene syringes and filtered through glass fiber filters (Gelman A/E) into acid-washed 150ml Nalgene bottles and placed on ice. Syringes were rinsed twice with stream water before filtering. At the same time water samples were collected for nutrient chemistry, a Hydrolab Datasonde 4 multi-probe was deployed to measure specific conductance and pH. The probe equilibrated for 5 minutes, after which values were recorded. Water samples for turbidity and total suspended solids (TSS) were taken from the thalweg using a DH-48 integrated water column sampler. Water samples for turbidity were analyzed immediately on a Hach 2100P portable turbidimeter which was field calibrated daily. TSS samples were taken back to the laboratory and filtered through pre-weighed, pre-ashed glass fiber (Gelman A/E) filters and re-weighed to determine TSS.

In the laboratory, samples for nutrient chemistry were frozen until analysis (<2 weeks). SRP, ammonium, and nitrate were analyzed at the University of Georgia, Institute of Ecology Stable Isotope/Soil Biology Laboratory (http://www.uga.edu/sisbl) on an Alpkem autoanalyzer following standard EPA guidelines.

Stream temperature was recorded hourly in all thirty streams from June 1999 – July 2000 using Onset Hobo temperature dataloggers (Onset Corporation, Massachusetts). Dataloggers were submerged in the streams and secured with metal cord. Loggers were stored within waterproof submersible cases.

Data were transformed as necessary to normalize variance. Correlation and regression analyses were used to assess relationships between land use and morphometric variables and water chemistry and temperature. The variables used for analysis represent a subset of uncorrelated morphometric and land use variables selected from a larger set of variables (Table 1). All analyses were performed using JMP statistical software (SAS institute).

Table 1. Morphometric and land use variables considered and used in correlation and regression models for predicting stream chemistry and temperature. The final variables used were selected to avoid collinearity.

Morphometric Variables Considered	Land Use Variables Considered
Basin Area, Stream Length, Channel Length, Local Relief, Narrowest Valley Top Width, Widest Valley Top Width, Catchment Slope, Drainage Density, Bifurcation Ratio, Length Ratio, Overland Flow Length, Basin Shape, Stream Frequency, Channel Maintenance Ratio, Relief Ratio, Relative Relief, and Ruggedness Index	1973, 1987, and 1997 Urban, Agricultural, Forested Land Use 1997 Riparian Urban, Agricultural and Forested Land Use within the whole watershed 1997 Riparian Urban, Agricultural, and Forested Land Use within 1km upstream of the study site Rates of change in urban and forested land use between 1973, 1987, and 1997
Morphometric Variables Used	**Land Use Variables Used**
Basin Area, Relative Relief, Local Relief	1973 Urban, 1997 Urban and Agricultural, 1973 High Density Urban (HDU), 1973 Cultivated/Exposed, 1987 Cultivated/Exposed, 1997 Cultivated/Exposed, 1km Riparian Urban and Agricultural Land Use, and Deforestation between 1973 and 1997 and between 1987 and 1997.

RESULTS

Across the 30 sites, average SRP ranged in concentration from 8 to 117 μg/L. Ammonium concentrations ranged between 5 and 91 μg/L and nitrate between 33 and 878 μg/L. Specific conductance ranged between 21 and 172 μs/cm and turbidity between 2 and 17 NTU. Mean annual temperatures ranged between 13 and 17° C, mean summer temperatures between 20 and 25° C, and mean winter temperatures between 6 and 12° C. The daily mean flux in temperatures (average daily max-min) were more variable: annual daily flux ranged between 1 and 7° C across all 30 sites; summer average daily flux between 1 and 9° C; and winter average daily flux between 1 and 9° C.

SRP was most significantly correlated with 1997 urban land use, relative relief, and riparian urban land use within 1km of the study sites (Table 2). Ammonium was most significantly correlated to riparian agricultural land use, 1997 whole watershed agricultural land use, and with relative relief. Nitrate, however, was most correlated with 1997 whole watershed agricultural land use, 1973 urban land use, and with the extent of deforestation between 1973 and 1997. Specific conductance was highly correlated with 1997 urban land use and with 1997 riparian agricultural and urban land use. Finally, TSS were most correlated with total relief, 1997 riparian agricultural land use and 1997 watershed urban land use.

There were fewer correlations between temperature and land use and morphometric measures. Mean annual temperature was correlated with 1973 cultivated/exposed land and mean annual flux with 1997 cultivated/exposed land. Average summer temperatures were correlated with 1997 urban land use and 1987 cultivated/exposed land, and average summer daily temperature flux was not correlated with any variable. Average winter temperatures were correlated with deforestation between 1987 and 1997, riparian agricultural land use, and 1997 whole watershed agriculture. Finally, winter daily temperature fluxes were correlated with 1997 cultivated/exposed lands.

Forward-selection multiple linear regression was used to select the best predictive models for chemical and temperature variables. SRP was predicted best with 1997 urban land use, although the variance explained was low (Table 3). Riparian agricultural land use explained more than 50% of the variance in ammonium. However, nitrate was predicted best with a combination of 1973 urban, 1997 agricultural, and 1973 high density urban land uses, which explained more the 50% of nitrate variability. Specific conductance was best explained with 1997 urban and riparian agricultural land use. TSS was best predicted with relative relief and 1997 riparian agriculture.

The same methods were used to predict mean temperature and temperature fluxes. There were 4 significant models (Table 3). Annual mean temperature was best explained with a combination of basin area and forest decline. Annual daily flux was best predicted with 1997 cultivated/exposed land use. Summer daily mean temperature was best predicted using basin area and 1997 urban land use, while winter daily mean temperature was best predicted with forest decline between 1987 and 1997 and riparian agricultural land use.

Table 2. Most significant correlations between watershed land use and morphometric measures and stream chemical and temperature variables. Values in parentheses are Pearson correlation coefficients (r) and indicate whether correlations are positive or negative.

SRP	1997 Urban (0.465), Relative Relief (-0.450), Riparian Urban (0.400)
Ammonium	Riparian Agriculture (0.736), 1997 Agriculture, Relative Relief (-0.440)
Nitrate	1997 Agriculture (0.557), 1973 Urban (0.492), 1973-1997 Deforestation (-0.458)
Conductance	1997 Urban (0.662), Riparian Agriculture (0.537), Riparian Urban (0.526)
Turbidity	None
TSS	Relative Relief (-0.642), Riparian Agriculture (0.604), 1997 Urban (0.523)
Annual Daily Temp	Basin Area (0.612), 1973 Cultivated/Exposed (0.388)
Annual Daily Temp Flux	1997 Cultivated/Exposed (-0.589)
Summer Daily Temp	Basin Area (0.490), 1997 Urban (0.409), 1987 Cultivated/exposed (0.400)
Summer Daily Temp Flux	None
Winter Daily Temp	Deforestation 1973-1997 (0.749), Riparian Agriculture (0.622), 1997 Agriculture (0.617)
Winter Daily Temp Flux	1997 Cultivated/exposed (-0.381)

DISCUSSION

There was a strong relationship between land use and stream chemistry in the Etowah basin. All of the stream chemistry variables were positively correlated with some measure of urban land use, except ammonium, which was most highly correlated with riparian agricultural land use. This interesting correlation between urbanization and increased nutrient and ion concentrations has been observed throughout the world (Smart et al. 1985, Suren 2000, USGS 1999). The strongest chemical response to urbanization was specific conductance, which has been suggested as an indicator of urbanization (Herlihy et al. 1998). We saw the strongest correlations between urban land uses and specific conductance, likely a response to the increased point and non-point sources of ions that exist in urban watersheds (Herlihy et al. 1998).

Phosphorus concentrations were strongly related to urbanization, a response seen in a nationwide study of land use and stream chemistry (USGS 1999). That

Table 3. **Multiple regression models for various water chemistry and temperature variables. Land use values are in percentage of watershed area. Forward stepwise multiple regression was used and the set of selection variables included in each regression are explained in the text.**

Dependent Variable	Best-fit Multiple Regression Model	R^2	p
SRP⁺	1 + 182(1997 Urban†)	0.27	**
Ammonium†	1 + 0.01(1997 Riparian Agriculture)	0.54	***
Nitrate	585 + 587(1973 Urban†) + 939(1997 Agriculture†) + 264(1973 High Density Urban†)	0.59	***
Conductance⁺	34 + 51(1997 Riparian Urban†) + 0.61(1997 Riparian Agriculture)	0.42	***
Turbidity⁺†	n.s.m.		
TSS†	0.69 – 0.83 (Relative Relief) + 0.461 (1997 Riparian Agriculture)	0.60	***
Annual Daily Mean	12.7 + 0.02(Basin area) + 3.6(Forest decline 1987-97†)	0.47	**
Annual Daily Mean Flux	4.4 – 10.4(1997 Cultivated/exposed†)	0.35	**
Summer Daily Mean	19 + 0.02(Basin Area) + 6.2(1997 Urban†)	0.38	***
Summer Daily Mean Flux	n.s.m.		
Winter Daily Mean	6.9 + 3.4(Forest decline 1987-97†) + 0.009(Riparian Agriculture)	0.68	***
Winter Daily Mean Flux†	n.s.m.		

(*p<0.05, **p<0.01, ***p <0.005.) SRP = soluble reactive phosphorus, "Flux" = average of daily maximum-minimum temperature for given time period, "Riparian" = land cover in 100m riparian buffer extending 1km above base of reach, n.s.m. = no significant model, ⁺outlier removed, † = transformed variable.

study focused on total phosphorus, whereas we found a strong relationship between urbanization and dissolved phosphorus. Higher dissolved phosphorus loads in urban streams versus forested streams has also been observed nationwide (Omernik 1976). This is likely a response to higher phosphorus loads coming from point sources, such as wastewater and industrial effluent, as well as non-point source phosphorus runoff from urban fertilizer application.

Nitrate increased significantly with urbanization and was best predicted with a combination of urban and agricultural land use. Interestingly, the urban land use most predictive was that from 1973. This suggests that older urban land uses influence current stream nitrate significantly. This could reflect aging septic systems that are contributing nitrogen to streams. Age of development is known to affect stream responses to urbanization (Hammer 1972), although water chemistry and age of urbanization has not been investigated per se. The contribution of agriculture is not surprising, given the large use of nitrogen fertilizers in both row crop, pasture, and lawn management, all of which constitute agriculture in this land use classification.

Ammonium was not related as strongly to urbanization. One possible reason may be the way agriculture is designated. Agricultural land use categorization includes grassland and golf courses, which are not considered traditional agricultural practices. Golf courses and lawn management have very high application rates of nitrogen-rich fertilizer, often higher than that associated with traditional row crop agriculture, which may be contributing to the high ammonium correlation seen with agriculture in the Etowah (Barth, 1995).

Finally, TSS increased with agriculture, but only with agricultural land use within riparian areas. This likely reflects the influence of contemporary near stream erosion on stream sediment loading. Riparian forest cover has been shown to reduce many of the chemical and physical effects of land use change in other studies, which argues for even greater protection of these valuable ecosystems in developing watersheds (Yoder 1999).

Temperature responses were not as significant as chemical responses. We did, however, find significantly higher average annual, summer, and winter stream temperatures associated with deforestation, urban land use, and riparian agricultural land use, especially after the natural influence of stream size was removed. These likely reflect increased insolation associated with loss of watershed tree cover as well as a decrease in cool groundwater flow that may result from increased watershed imperviousness (Pluhowski 1970, LeBlanc et al. 1997). The only significant predictive relationship between temperature flux and land use was between annual daily flux and cultivated/exposed land, and it was negative. This may be due to a greater impact of forest clearing on minimum temperature than on maximum temperatures, thereby increasing mean temperatures while at the same time reducing the daily range.

Overall, we identified a number of predictive relationships between land use and stream chemistry and temperature. The overall strength of these varied among parameters, but reflects the fact that urban growth results in predictable increases in stream nutrients, other ions, and temperature. These changes will affect stream biological communities in a number of ways ranging from individual mortality and life history alteration to changes in stream primary productivity and nutrient cycling.

LITERATURE CITED

Allan, J.D. 1995. Stream Ecology: Structure and Function of Running Waters. Chapman and Hall, New York.

Barth, C.A. 1995. Nutrient movement from the lawn to the stream? Watershed Protection Techniques 2:239-246.

Hammer, T.R. 1972, Stream channel enlargement due to urbanization. Water Resources Research 8:1530-1540.

Herlihy, A.T., J.L. Stoddard, and C.B. Johnson. 1998. The relationship between stream chemistry and watershed land cover data in the Mid-Atlantic region. Water, Air, and Soil Pollution 105:377-386.

Hynes, H.B.N. 1960. The Biology of Polluted Waters. Liverpool University Press, Liverpool, England.

LeBlanc, R.T., R.D. Brown, and J.E. Fitzsimmons. 1997. Modelling the effects of land use change on the water temperature in unregulated urban streams. Journal of Environmental Management 49:445-469.

Leigh, D.S., M.J. Paul, M.C. Freeman, B.J. Freeman, E.A. Kramer, A.D. Rosemond, C.M. Pringle, and C.P.Lo. 2001. Overview of land use and geomorphic indicators of biotic integrity in the Etowah River Basin, Georgia. In Hatcher, K.J. (ed.), Proceedings of the 2001 Georgia Water Resources Conference, University of Georgia, Athens, Georgia.

Lenat, D.R. and J.K. Crawford. 1994. Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. Hydrobiologia 294:185-199.

Leopold, L.B. 1968. Hydrology for urban land planning – a guidebook on the hydrologic effects of urban land use. USGS Circular 554.

Meybeck, M. 1998. Man and river interface: multiple impacts on water and particulates chemistry illustrated in the Seine River basin. Hydrobiologia 373/373:1-20.

Omernik, J.M. 1976. The influence of land use on stream nutrient levels. EPA-600/3-76-014.

Pluhowski, E.J. 1970. Urbanization and its effect on the temperature of streams on Long Island, New York. USGS Professional Paper 627-D.

Smart, M.M., J.R. Jones, and J.L. Sebaugh. 1985. Stream-watershed relations in the Missouri Ozark Plateau province. Journal of Environmental Quality 14:77-82.

Suren, A.M. 2000. Effects of urbanisation. In Collier, K.J. and M.J., Winterbourn (eds.) New Zealand Stream Invertebrates: Ecology and Implications for Management. New Zealand Limnological Society, Hamilton, New Zealand.

United Nations Population Division (UN). 1997. Urban and Rural Areas 1950-2030 (the 1996 revision). United Nations, New York.

United States Census Bureau 2000. http://www.census.gov.

United States Geological Survey (USGS) 1999. The quality of our nation's waters – nutrients and pesticides. USGS Circular 1225.

Yoder, C.O., R.J. Miltner, and D. White. 1999. Assessing the status of aquatic life designated uses in urban and suburban watersheds. in EPA-625/R-99/002